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The deepest impacting discovery of the XX century derived from food science

Abstract

The Haber-Bosch process, an industrial fixation of atmospheric nitrogen into crop fertilizers, enabled increasing rates of food production soon after the First World War. The process contributed to alleviate famine episodes and to reduce the occurrence of sicknesses derived from malnutrition. Higher provision of food and health improvement in the second half of last century led to increasing rates of world population and the emergence of health problems derived from excess calory intake. Overpopulation and obesity are examples of present-day crises with roots in the Haber-Bosch process. Incoherently, despite the deep impact of the process in recent history, both Haber and Bosch are prominent characters of science history almost unknown by people all over the world.

Keywords: nitrogen fixation, crop fertilizers, famine, overpopulation, obesity

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Introduction

In the last 120 years, deep transformations took place in the world, resulting from scientific, technological, and social developments. In this period the world witnessed impacting advances such as the introduction of the cinema, television, airplanes, telephones, computers, satellites, air space flights, cell phones and internet communication, among many other developments. Fundamental advances in pharmacy and medicine in the period include antibiotics, X rays, non-invasive surgeries (e.g. cardiac catheterization), diagnostic imaging (e.g. ultrasound, tomography and resonance), discovery of a multitude of ever advancing and effective drugs and the remarkable recent pharmaceutical advances that enabled the production of vaccines against coronavirus in a surprising short period of time. Major scientific advances occurred, such as the theory of relativity, radioactivity, nuclear power, the discovery of the black holes, elucidation of the DNA structure and consequent revolutions in the biological and health sciences. Gradual and profound modifications have occurred in international relationships, such as the end of colonialism and the onset of globalization, as well as in human relationships, with advances in the social position of women and issues involving race and gender.

Relevant advances in food technology also took place in the XX century. The Institute of Food Technologists lists some important achievements. Some of them are mentioned in continuation: a) vacuum packaging and ionizing radiation, both contributing to extended shelf life and no nutrient loss (1900-1905); b) large scale commercial pasta production in the USA (1910); c) quick freezing processes and blanched frozen vegetables; salt fortified with iodine (1924); d) freeze-drying process for food preservation (1930); e) mass production of food using automation, a step taken under pressure of the necessity to ship overseas massive quantities of food to the military (1940s); f) controlled atmosphere packaging, which permitted delaying food ripening and spoilage (1960s); g) modified-atmosphere packaging, by introducing nitrogen and thus increasing shelf life and protection form spoilage, oxidation, dehydration, weight loss and freezer burn (1980s); h) wide use of Hazard Analysis Critical Control Point measures (1990s).[1]

Given so many striking and influencing advances, a question may be put forward: *what was the most important achievement over the last 120 years, the one causing the deepest impact in recent history?* The answer to this question was given by Vaclav Smil.[2,3] In his opinion, the most impacting scientific discovery in the XX century was the Haber-Bosch process, which enabled the production of ammoniacal fertilizers from atmospheric nitrogen. He based his opinion on the analysis of the recent evolution of world population. The first time the world population reached 1 billion only was in 1800. With the influence of Industrial Revolution, the second billion was conquered in 1930, not long after the widespread industrial use of the Haber-Bosch process.[4] Dramatically, from then on, an explosive rise of the curve took place, the population rapidly jumping to 6 billion in 2000 and now, only 20 years afterward, peaking at 7.8 billion (Figure 1).

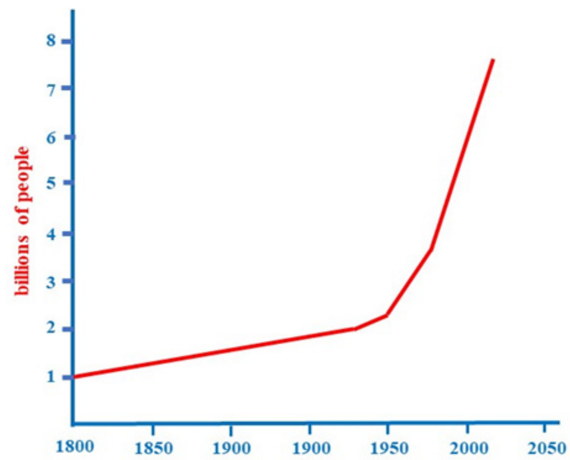

Figure 1 Evolution of world population.

Main constraint for the increase of world population

Like all living beings, humans have a natural impulse to generate descendants. According to the theory of natural selection, the main obstacle for increasing animal and plant populations is limited availability of food in the environment. Darwin wrote that a pivotal factor influencing his ideas was the theory of world population by Thomas Malthus (1766-1834), explained in his book *An Essay on the Principle of Population* (1798). This theory assumed that the farmland practiced until then had been unable to provide food enough to satisfy the demands of the increasing human population. Up to Malthus' times, consequences of this failure were often translated into frequent episodes of famine in many parts of the world and shortage of food even in rich European countries. In fact, from the dawn of history, chronic shortage of food and malnutrition have been the scourge of humankind.[5] Presently, people in several parts of the world are still afflicted with chronic starvation and food shortage.[6] Malthus provided mathematical basis to his arguments, proposing that human population tend to grow in geometrical progression, while the availability of food at most increases in arithmetical progression. Malthus' theory of population had a profound impact among experts from many fields of studies in the XIX and early XX century.

Until the beginning of last century, the limiting factor for higher increases in food production was the shortage of crop fertilizers. The close dependence of crop production on the use of fertilizers may be quickly grasped on data of FAO[7] (Figure 2), referring to world agricultural accomplishments over the beginning of the "Green Revolution".[8] Predominant crop fertilizers used at the time were produced with guano, a product derived from excrements of Peruvian marine birds. Guano is an excellent source of nitrogen, potassium, phosphorus, and sulfur, among other minerals. Among the chemical elements in fertilizers, the one in higher demand is nitrogen. Proteins contain16% of the element, while DNA and RNA its proportion is 14%. In the beginning of last century, prospects for the continuity of provision of guano were dark, due to an imbalance between shortages of the product and increasing demand. Devastating famine episodes, with multiple human casualties, were repeatedly reported: 11 million people in China, 9 million in India, 1 million in Brazil (1870-1880); 5 million in Congo, 7 million in India, 1 million in Brazil and China (1885-1900).[6] Therefore, scientists and public authorities at the time felt the urgent need of the discovery of an abundant and sustainable source of nitrogenous fertilizers.

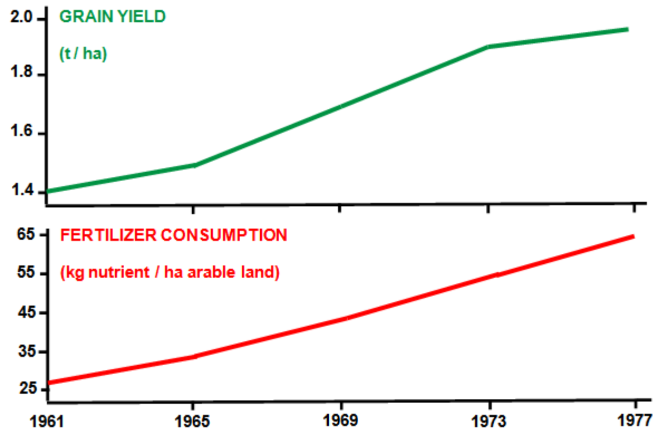

Figure 2 Dependence of crop yields on the use of fertilizers. Average of world agriculture data. Based on FAO Fertilizer and Plant Nutrition Bulletin.[7]

And the air was turned into bread

Nitrogen is abundant (78%) in the atmospheric air, but plants cannot assimilate elementary nitrogen (N_2). Only combined forms of nitrogen, such as ammonium (NH_4^+) and nitrate (NO_3^-) are absorbed and metabolized by plants. Life on Earth depends on the labor of nitrogen fixing microorganisms, such as some bacteria and cyanobacteria, which enzymatically and at environmental conditions convert atmospheric N_2 into NH_4^+, which is then used by photosynthesizing organisms in the synthesis of amino acids and proteins.[9] Till the beginning of the last century, no chemical process had been devised to convert atmospheric N_2 into a compound applicable as fertilizer in agriculture. "When this is done", was then commented "it will be like converting air into bread".

A most remarkable feat was achieved by Fritz Haber (1868-1934), a chemical scientist at the Karlsruhe University. In 1909, he devised a laboratory method for the synthesis of liquid ammonia (NH_3), starting from air N_2 and methane (natural gas). The latter was used as source of hydrogen in the synthesis. The process required elevated values of both pressure (200 atm) and temperature (400-450ºC), in addition to catalysts, represented by osmium and uranium. The reaction is summarized as follows:

$$N_2\text{(gas)} + 3\,H_2\text{(gas)} \rightleftharpoons 2\,NH_3\text{(gas)} \quad \Delta H = -92\text{ kJ mol}^{-1}$$

To meet the requirement of large-scale production, Haber's method had to be adapted for industrial work. This task was assumed by Carl Bosch, a chemist and engineer working at BASF (Badische Anilin und Soda Fabrik, in Ludwigshafen). It involved the development of plant and industrial equipment capable of standing up high pressure and elevated reaction temperatures. The catalyst was replaced by a lower costing metal (iron), plus additives. Ammonia was eventually obtained in large-scale amounts. The industrial synthesis of ammonia is known as the Haber-Bosch process. The next step was the development by Carl Bosch and collaborators of methods for production of nitrogen fertilizers for use in agriculture. The enterprise was successful and increasing amounts of fertilizers started being provided to practically every country in the world. The achievement may be interpreted as the agent bringing about the disruption of the chains of the Malthusian limitation. Fritz Haber was honored with the Nobel Prize in Chemistry in 1915, and Bosch in 1931.

Increased human longevity and health improvement are among the benefits derived from the Haber-Bosch process. The process kept pace with growing demands of fertilizers, needed for new gains in food production after the World War II, by means of innovations in agriculture such as the "Green Revolution",[8] mechanization of the agriculture, and advances in the use of herbicides, pesticides, and biological control. The combination of all these advances led to the upward inflexion of the curve of the world population (Figure 1). The way was then open to further improvements, expected to be brought about by the application of DNA technologies in agriculture.[10] It is estimated that presently 50% of the nitrogen in human tissues derive from the Haber-Bosch process.[11] Most of this nitrogen derives from food produced in terrestrial environments. Much nitrogen in human tissues still derive from biological fixation, occurring mainly in aquatic environments.

Haber-Bosch process: major trigger of present-day crises

We now face serious problems that represent the opposite of the burdens tormenting humanity up to the beginning of the XX century. At that time, chronic food shortages were the root for famine episodes and sicknesses due to malnutrition. The early agricultural and technological conquests of the XVII - XIX century (British or Second Agricultural Revolution) and, chiefly, the Haber-Bosch process improved public health and enabled the provision of foods in higher

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and higher amounts and variety. The scarcity of food over most of the history of mankind led to the notion that being fat was an admired aesthetic physical pattern, which was often reflected in arts, literature, and medicine. Until the first half of last century, most people all over the world were thin, not rarely, skinny; fat people were rare. Many young women wanted to put on weight, believing that in this way they would turn out more attractive to men. At the time, fat women often belonged to rich families, and assumedly were more apt to give birth to many children. Men also wished to father many children, who could help in home labor and in the sustainment of the family. Advertisements of popular medicines before World War II guaranteed women extra kilos in a short period of time.

Obesity, with well-defined pathological consequences, is less than a century old.[5] Combined with sedentary habits and genetic propension, overconsumption of food (in particular, fast food, industrialized and high calory food) is the main cause of obesity, a chronic disease so common in our times, often associated with increased mortality. The availability and diversity of fresh and semi-prepared convenience food in today's supermarkets, especially in large cities of all continents, were unthinkable until relatively recent times. High rates of obesity started being common in USA. Soon afterward, the problem spread to many urbanized areas of the world. A 2019 official search reported that 60% of 20-year-old people and above are overweighted, and 25% are obese in Brazil.[12] The Haber-Bosch process was the main factor enabling the recent high abundance of food in many parts of the world. Thus, it may be assumed as a major effect triggering obesity in the world.

Only recently a famous biblical precept has been almost fully achieved: "As for you, be fruitful and increase in number; multiply on the Earth and increase upon it" (Genesis, 9:7). As seen on Figure 1, the multiplication of human beings never reached the rate characterizing the last 60 years. Due to a high uplift on the availability of food and other resources, the Haber-Bosch process turned out the detonator of world population explosion.[2] Unfortunately, humans advanced too far ahead toward the fulfilment of the biblical precept, leading the world population to dangerous proportions. Overpopulation is one the most serious challenge for scientists and public authorities. According to many experts, the maintenance of the present rate of rise of the world population represents a serious risk to the very survival of our species. It is urgent to lessen the present rate of population rise. The Earth, formerly imagined as an immense world, is short to becoming too small to provide food and other essential issues for all humans.

Haber-Bosch process: a neglected prominent scientific and technological achievement

Several milestones have been recognized in agricultural history: 1) Neolithic Revolution, or First Green Revolution (12,000 years ago); 2) British or Second Agricultural Revolution (XVII-XIX century); 3) Green Revolution, or Third Agricultural Revolution (1950-1970). Despite the profound impact in world history in the XX century, first alleviating the problems of scarcity of food, and hence improving human health and longevity, but later becoming the root of present-day dangerous crises, the Haber-Bosch process has not been included as one of the landmarks in agriculture history.

It is incoherent that Fritz Haber has not been included as a celebrity, not only in agriculture, but also in science history. His importance for the development of food production is at least comparable to that of Norman Borlaug (celebrated North-American agronomist, launcher of the Green Revolution in the 50's and winner of Nobel Peace Prize of 1970). In fact, the impact of synthetic fixation of air nitrogen by Fritz Haber in the recent world history is far utmost than the contribution of any other scientist of the XX century. All students in the world learn at least fundamentals of biological nitrogen fixation. However, an astounding number of well-educated people has never heard or read anything about Fritz Haber, Carl Bosch, and the breakthrough they accomplished in science and technology.

Conclusion

The overall unfamiliarity of the Haber-Bosch by people in general is a fact pointing out the necessity of the disclosure of the facts related with the two prominent Nobel laureate scientists and their contribution to science and technology. The history of science divulged to students and common people should be amended with the inclusion of the Haber-Bosch process among the main achievements of agriculture and science in the XX century.

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Conflicts of interest

The authors declare that there was no conflict of interest.

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